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It is expected that the complete paper will appear as a publication of the Carnegie Institution of Washington.

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SECOND TYPE STARS OF LOW MEAN DENSITY

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The rôle played by stellar densities in the theories of the order of stellar evolution is easily recognized. If the development of a star uniformly follows the spectral sequence B, A, F, G, K, M, that is, if in contracting through the agency of its own gravitation its light changes in color steadily from bluish white to red, then the mean density of the B and A type stars must naturally be less than that of the redder stars. But, on the other hand, if the earlier as well as the later stages in a star's evolution are characterized by the second and third type spectra (F, G, K, M), the density of the redder stars should have both small values and large values relative to the bluer stars.

There are two principal lines of observational evidence that indicate the existence of two orders of densities for second type stars:

1. The recognized existence of enormous differences in the absolute brightness of red or yellow stars of essentially identical spectra leads immediately to the conclusion that the volumes also differ greatly. Now since stellar masses so far as known have not very greatly differing values, we are lead to believe that the disparity in size must be accounted for by large differences in mean density. For instance, the density of our sun, which on this interpretation must be considered a body relatively advanced in age, may be from a thousand to a million times greater than that of a star of great intrinsic luminosity, such as Alpha Aurigae, which has a similar spectrum and presumably therefore a comparable suface temperature. An objection to this argument in favor of very low densities for some of the redder stars may be that our information relative to stellar masses is insufficient to prove that the large volumes are not to be attributed to large masses with normal densities.

2. The densities of eclipsing binaries, however, can be determined directly, independently of the unknown masses; and recent studies of

this class of variable stars have given results for different spectral types with considerable certainty. The average density of first type stars (B, A) is about 0.15 on the solar standard, while none exceeds the sun in density and none is less than one-hundredth as dense. Also a number of second type stars are found to be much denser than the average first type star, even exceeding the sun in rare cases. This condition fits in with either theory of the order of stellar evolution. Hence for the purpose of differentiating between the rival hypotheses it is of importance to know how definitely we can say that there are also stellar densities much lower than any known for A and B type stars. The present communication outlines the data now in hand relative to low-density eclipsing stars of the second spectral class.

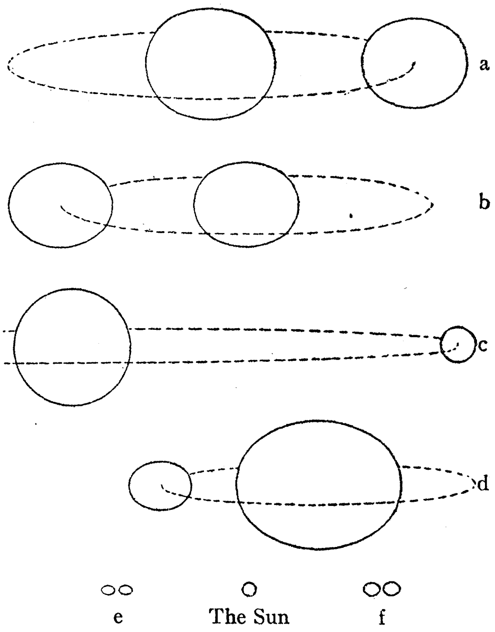
The values of the densities already derived for the stars considered in this note refer to the individual components of each system, and therefore, since for such purpose knowledge of the relative dimensions and masses is necessary, the results are involved with rather complicated computations of the orbital elements. It is possible, however, to derive upper and lower limits of the mean density of each system without the necessity of any data relative to the stars or their light curves other than the period of revolution and the duration of eclipse, which are the two quantities most commonly and most easily obtained for eclipsing variables. In the more detailed discussion of this subject the following simple relations are obtained, which give in a circular orbit the mean density, d_0, in terms of the sun:

$$d_0 \leqq \frac{0.054}{P^2 \sin^3 \dfrac{2\pi t}{P}}, \qquad d_0 > \frac{0.216}{P^2 \left(1 + 3 \sin^2 \dfrac{2\pi t}{P}\right)^{3/2}}.$$

The quantities P and t are the period of revolution and the semi-duration of eclipse. In very exceptional cases the second relation may give too high a lower limit, but never a value as much as twice too large.

The above formulae are especially suitable for the easy computation of the order of the density in systems of long period, which are usually also the cases where very low densities are found. With their aid results for five low density binaries of the second spectral type were readily determined and the values found to correspond closely to those computed rigorously from the orbital elements. The light curves on which the results are based are from various sources, and, while not of the first order of accuracy, are probably sufficient in all cases to leave no doubt that the low densities really exist. Three independent classifications of the spectra were made at the Harvard College Observatory.

In the accompanying figure is given a comparative diagrammatic representation of some of these giant eclipsing double stars and also of the two systems of highest known density. The key to the diagram gives the data relative to densities and spectra. Making the reasonable assumption that the mass of the sun is sensibly equivalent to the mass of one component of any of the double stars, then the sun can be drawn to scale, as at the bottom of the diagram. If its mass is but one eighth that of a single component, its diameter in the diagram should be one-half as great; if eight times as massive as assumed, its diameter should be doubled. The true dimensions of the stars relative to the sun are probably well within these limits. It is to be noticed that the components of five of the six binaries are elongated in the line of centers.



Eclipsing binaries of low and high density. The mass of each component is assumed equal to that of the sun.

a. SX Cassiopeiae; period $36^{\text{d}}.572$; spectrum G3; density 0.0003. Reduced to one-half.

b. RX Cassiopeiae; period $32^{\text{d}}.316$; spectrum Ko; density 0.0005. Reduced to one-half.

c. RZ Ophiuchi; period $261^{\text{d}}.9$; spectrum F8; density 0.001. Reduced to one-fourth.

d. W Crucis; period $198^{\text{d}}.5$; spectrum Gp; density 0.000002. Reduced to one-eighth.

e. W Ursae Majoris; period $0^{\text{d}}.334$; spectrum G; density 1.84.

f. U Pegasi; period $0^{\text{d}}.375$; spectrum F?; density 0.75.

Summary. Because of its bearing on the question of the order of stellar evolution, the density of stars of the second spectral type has been discussed from the standpoint of the dependability of the observational and theoretical work that is the basis of the derivation of occasional extremely low values. The evidence discriminating between the two principal theories seems very definite, but further observational work would materially strengthen the case. The light curves of the variable stars involved, the relevant tabular data, and the derivation of certain density relations will appear in an early number of the *Astrophysical Journal.*